Chapter 2

The Shortwave Transmitter Schwarzenburg and the Surrounding Population

2.1 Introduction

Schwarzenburg is a district of the Canton of Bern, 20 km south of Switzerland's Capital Bern in the Prealps. It is divided into four municipalities: Albligen, Guggisberg, Rüschegg and Wahlern. The Shortwave Transmitter Schwarzenburg is located on the territory of the municipality of Wahlern and about 2 km east of Schwarzenburg, the District's administrative center and its largest town. The countryside around the Shortwave Transmitter is characterized by a small plateau surrounded by hills of about 100m altitude. The Alps rise approximately 5 km south of the Shortwave Transmitter.

2.1.1 History and Technical Background

The Shortwave Transmitter Schwarzenburg broadcasts programs of Radio Swiss International, the purpose of which is to inform the world and the Swiss living abroad about Switzerland and its culture. The transmitter is run and maintained by Telecom Switzerland (PTT).

The Shortwave Transmitter Schwarzenburg was built in 1939 and since then gradually extended. The main antenna, a star-shaped curtain antenna, dates back to 1954 and is exploited with a maximum power of 3 times 150 kW. In 1971 the LOG PER antenna, a rotating antenna, had been added. It has a power of 250 kW and serves as a substitute of another shortwave transmitter at Sottens in case of interruptions due to maintenance works. Since having been put into operation in 1939 the Shortwave Transmitter has been broadcasting exclusively to overseas regions. The transmission direction for overseas has remained unchanged up to now. The transmission directions and broadcasting schedules have not changed materially since 1985. The broadcasts are transmitted in blocks of usually 2 hours. One target zone at a time are served simultaneously with up to 3 transmitters of 150 kW operating at different frequencies.

In addition the Transmitter is also used for air radio and wireless telephone communications. These require transmission powers far below the power levels required for broadcasting and can therefore be neglected.

2.1.2 The Surrounding Population

Demographic and cultural aspects

The district of Schwarzenburg had 9509 inhabitants in 1950. 4825 (51%) persons lived in the municipality of Wahlern. At the census in 1990 the municipality of Wahlern had 5732 inhabitants, which meant an increase of about 20%. The municipality of Wahlern is divided into seven school districts: Schwarzenburg, Waldgasse, Zumholz, Wyden, Tännlenen, Moos and Steinbrünnen. The Transmitter is located at Tännlenen. Although the total population of Wahlern has been generally increasing, every school district shows its own demographic tendencies. From 1950 to 1990 the population at Tännlenen declined from a total of 920 inhabitants to 702, a decrease of 31%. The other rural school districts such as Waldgasse, Zumholz, Wyden, Moos and Steinbrünnen show a similar pattern. The general increase in the total population in the municipality of Wahlern is therefore due to an increase in the town of Schwarzenburg, the main trading place. In Schwarzenburg itself the population grew from 1728 inhabitants in 1950 to 3204 in 1990 (these figures are based on personal communication with the municipality of Wahlern). Although Schwarzenburg is a rural area, about 2/3 of its population work in the services sector; about 20% work in agriculture and the remaining 13% are active in the industry and trade sectors. About 50% of the concerned population declared to be self-employed. About 16% of the population continued their education at a high school or equivalent level, which is somewhat less than the Swiss average (own observations, see interview study 1992). In Switzerland, about 24% of adolescents continue their education, after finishing the 9 compulsory school levels (source: Statistisches Jahrbuch der Schweiz, 1990).

2.2 How the study came about

2.2.1 The Petition

Since the 1970s people living in the surroundings of the Shortwave Transmitter have increasingly complained about negative effects on their health. Several attempts were made to eliminate disturbances of electrical equipments and to initiate epidemiological surveys of possibly related illnesses.

On the 2nd of March 1990, a petition signed by 195 persons living in the surroundings of the Transmitter was submitted to the Head of the Federal Department of Traffic and Energy. The petitioners required a scientific evaluation of their health problems, which they related to the effects of the Transmitter's electromagnetic fields. In October 1990, the Federal Department of Traffic and Energy set up a study group charged with the task to evaluate the feasibility of an epidemiological survey and to develop a corresponding concept.

2.2.2 Supervisory bodies

The Study Group

In April 1991, the Study Group started its work under the leadership of Dr. J. Cattin, Section of Energy at the Federal Office of Energy. Its members were:

- Prof. Dr. Th. Abelin, Department of Social and Preventive Medicine, University of Bern, Switzerland.
- Dr. J. Baumann, Federal Office of Environment, Forests and Landscape (Environmental Protection).
- R. Coray, Swiss Telecom PTT, Radiocom Directorate.
- Dr. M. Jungck, Federal Office of Public Health.
- Dr. H. Howald, Bernese Institute of Occupational Medicine.
- Dr. H. Mathys, Section of air pollution, Cantonal Office of Industry, Trade and Work, Bern.
- Dr. V. Mercier, Federal Office of Public Health.
- Dr. A. J. Seiler, Cantonal Medical Officer (Kantonsarzt), Cantonal Department of Public Health and Welfare, Bern.
- Secretary: E. Bur, Section of Energy, Federal Office of Energy.

After two meetings the team concluded that an epidemiological survey could be realized.

The Department of Social and Preventive Medicine of the University of Bern headed by Prof. Dr. Th. Abelin and the Bernese Institute of Occupational Medicine directed by Dr. H. Howald were charged with the development of a concept for the survey. Telecom Switzerland was engaged to perform exposure measurements under the supervision of the Institute of Field Theory and High Frequency Technology of the Federal Institute of Technology Zürich. The Study Group appointed two expert groups for the epidemiological survey: on the one hand the exposure measurement group, on the other hand the medical and biological group. Their objectives were to evaluate the data collection and measurement instruments, to supervise field and laboratory activities, and to suggest conclusions and recommendations.

The medical and biological group

Chaired Prof. Dr. Th. Abelin this group discussed the methodology and the results of the epidemiological survey. Members were Dr. A. J. Seiler, Dr. V. Mercier, Dr. M. Jungck. Dr. Ch. Griot and Dr. K. Staerk from the Institute of Virology and Immunoprophylaxis joined the Group later.

The exposure measurement group

Chaired by Prof. Dr. Th. Abelin this group discussed issues connected with the exposure assessment. Members were Mr. R. Coray and Dr. J. Baumann.

Supervision of Field exposure measurements

The first part of the exposure assessment in 1992 was supervised by the Institute of Field Theory and High Frequency Technology of the Swiss Federal Institute of Technology Zurich. In 1993 the exposure assessment was supervised by the Laboratory of Electromagnetics and Acoustics of the Swiss Federal Institute of Technology Lausanne.

The participating institutions

In 1993 the decision was taken to evaluate more profoundly the situation around the Shortwave Transmitter, with the focus on the reaction of melatonin levels in humans as well as in dairy cows. The Division of Protein and External Analysis (Division Head: Prof. Dr. med. H. Gerber) of the Central Chemical Laboratory of the University of Bern (Dept. Heard Prof. J. P. Colombo), Inselspital, Switzerland, and Repromed, Hamburg Germany (Head Dr. B. Manz), were therefore engaged to test urinary and salivary samples for 6-Hydroxy-Melatonin-Sulfate and Melatonin, respectively.

Chapter 3

Study Questions and General Study Design

Th. Abelin, E. Altpeter, Th. Krebs, D. H. Pfluger

Abstract:

In this chapter the study questions are formulated, the designs for the different parts of the Study are developed, laboratory methods and arrangements are described, exposure classification and assessment principals are outlined and the basic ideas of the applied statistics are presented.

3.1 Study Questions

The main purpose of the study was to answer the following questions:

1. Are health complaints and ill health more frequent in the close surroundings of the Shortwave Transmitter Schwarzenburg than in more distant areas ?

2. If yes, are they biologically related to the electromagnetic fields (EMF) of the Transmitter ?

3. If there is any suspicion that the health of the population might be affected by EMF, is there a plausible mechanism explaining this?

3.1.1 Study I

Having reviewed the literature for signs, symptoms and diseases we found only few reports on potential adverse effects in the nonthermic range. The hypothesis, therefore, was deduced by including those observed in the thermic range:

1. psychovegetative symptoms such as palpitations, vertigo, headache, tiredness, nervosity, lack of appetite, sleeplessness, perspiration, reduced concentration, amnesia, depression, emotional instability.

2. changed blood pressure

3. anemia, increased tendency to bleed

4. increased frequency of infection

5. sexual disorders: lowered fertility, lower birth weight, teratogenesis

6. cancer, e.g. lung cancer

7. morbus Parkinson

8. meningitis

9. cataract

Apart from thermal effects of EMF we have little evidence of biophysical interaction (see Study II). For practical reasons we formulated three alternative testable hypotheses:

1. The Transmitter has, due to its EMF, a direct influence on the physiologic functions of humans as well as animals. This causes an increase in complaints and ill health.

2. Complaints and ill health are caused psychologically by the transmitter's mere presence and public discussion of possible health-effects.

3. Complaints and ill health are induced psychologically by disturbances of electrical equipment which cause stress to the population exposed to the immissions.

In order to answer these questions a preliminary study (Study I) was designed and executed in 1992. This study was focused on:

1. spatial distribution of malignancies

2. spatial distribution of psychosomatic symptoms and their time dependence

3. estimation of the reliability of self reported symptoms and signs

4. dose-response relationship

3.1.2 Study II

As Study I suggested an association with the population health, a plausible biophysical interaction was investigated in a subsequent study (Study II). Its purpose was:

1. to examine the hypothesis, that melatonin, a product of the pineal gland, and suspected regulator of sleep-wake rhythm is effected by EMF emitted by the Schwarzenburg transmitter,
2. to validate the self-reporting of hypertension and
3. to examine the possibility of effects on mental functioning of exposed schoolchildren.

The questions, in more detail, focused on:

1. Acute effect of EMF and of the removal of EMF-exposure on sleep patterns in humans
2. Chronic and acute effect of EMF on urinary 6OHMS levels in humans, including the validation of the urinary 6OHMS test
3. Relationship between sleep pattern and 6OHMS levels in early morning urine.
4. Chronic and acute effect of EMF on salivary melatonin levels in cows
5. Validation of self-reported hypertension in man
6. Pattern of promotion rates from primary to secondary school level.

3.2 General Design

3.2.1 Study I

The basic ideas of the design are:

- *Cross-sectional study*: three population groups, A, B and C, with high, medium and low exposure were questioned about their health status in a personal structured interview and completed segments of standardized personality testing. Exposure measurements on 55 sites around the Transmitter during 24 hours confirmed this classification and permitted more differentiated analyses.
- *Semi-experimental study*: during 3×10 days a modified emission scheme was put into effect. A subsample of the population kept a diary on symptoms in order to verify the interview responses and to analyze their frequencies during the exposure period, and their association with the modified emission scheme.

Exposure Classification

In order to test the three hypotheses stated earlier (see page 26), which in fact distinguish between a biophysical and a psychological effects of the Transmitter, three zones around the Transmitter were defined:

Zone C: A population considered unexposed and with comparable socioeconomic structure was allocated at Lanzenhäusern and in the south-west of Schwarzenburg (see Figure 3.1)

Zone B: People living inside the circle C_B with center (595 400 / 184 590) and radius $r = 1500m$ were considered to be exposed. The circle C_B corresponds approximately to the 1 V/m immission isoline. This population was divided into groups A and B in order to form equally sized population groups with different exposure. This led to an inner circle C_A with radius $r = 900\ m$ and center (595'750 / 185'000). People living outside the circle C_A and inside C_B were assigned to Zone B (see Figure 3.1).

Zone A: People living inside the circle C_A were assigned to Zone A (see Figure 3.1).

In each of these zones exposure was measured on characteristic sites (see section 4.3).

Exposure Scheme

During 3 10-day periods persons under survey kept a diary on symptoms. During these periods the transmission directions were changed in random fashion between the ordinary and an experimental scheme. In the experimental scheme the directions were turned by 180 degrees with regard to the ordinary scheme. Neither the modified directions, nor the sequence of ordinary and experimental broadcasts was known to the study population or to the investigators.

Shortwave Transmitter Schwarzenburg: Outdoor Magnetic Field Strength

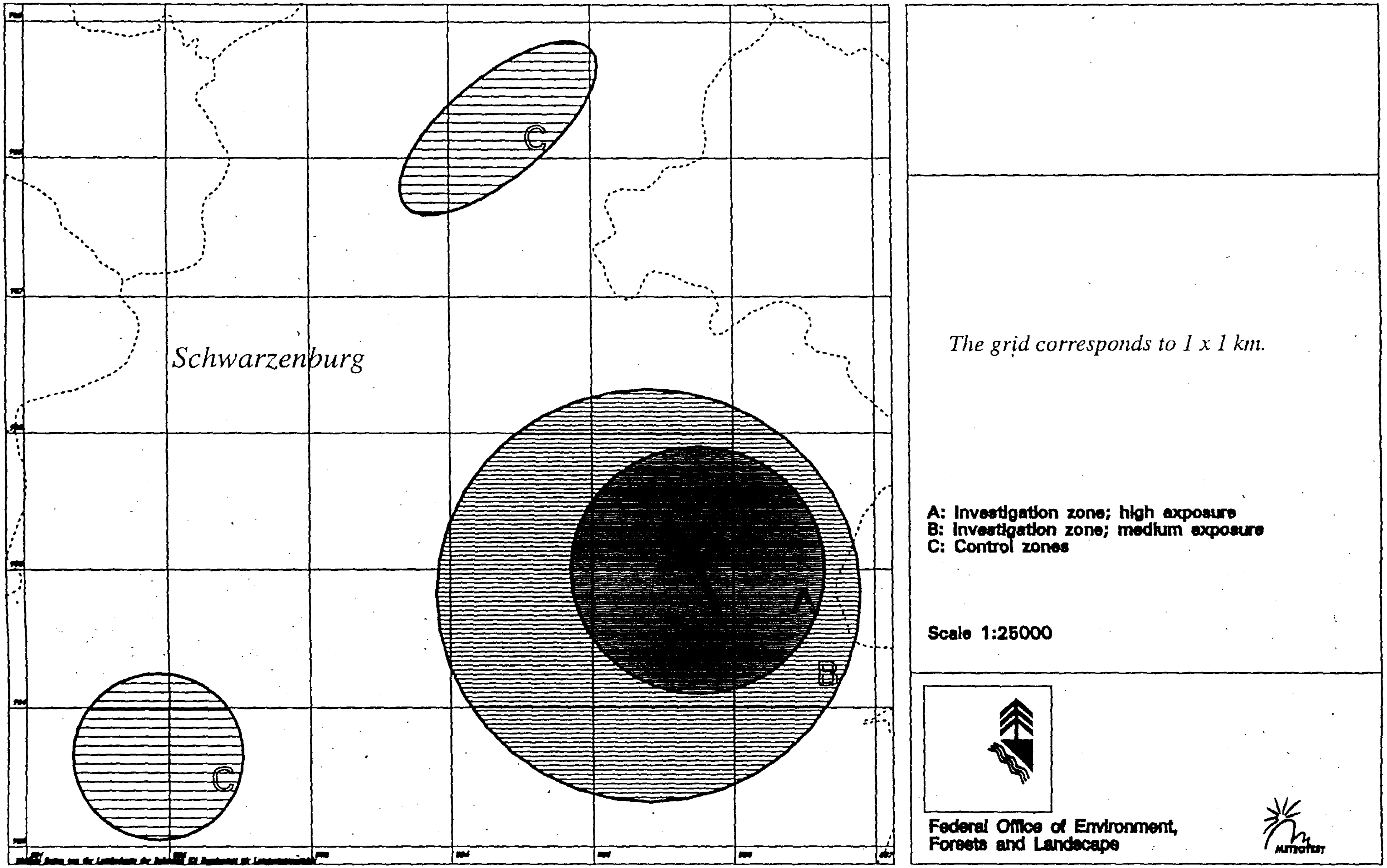

Figure 3.1: Exposure zones.

3.2.2 Study II

Study II consists of 4 substudies:

1. Melatonin excretion in the surroundings of a shortwave radio transmitter (study in humans)
2. Melatonin excretion in the surroundings of a shortwave radio transmitter (study in bovines)
3. Melatonin excretion and sleep disorder in the surroundings of a shortwave transmitter
4. Verification of blood pressure values in the surroundings of a shortwave radio transmitter
5. Performance and well-being of schoolchildren in the surroundings of a shortwave radio transmitter.

The *melatonin studies* have a common design. During ten days humans and cows were under survey. Data collection started on the 5th of September, 1993, at 7.30 p.m. On the 7th of September, at 11.00 a.m. the Transmitter was switched off, at 11.00 a.m. on the 10th of September it went back into operation. The data collection ended in the morning of the 14th of September, 1993. During these ten days early morning urine of humans and nightly salivary samples of cows were collected in two-hour intervals, starting at 7.30 p.m., for 6OHMS or melatonin testing. During the 3-day period with the Transmitter switched off background exposure was measured. In the course of the following six weeks indoor exposure was measured by Telecom Switzerland. The basic idea in the human study was to follow a sample of 60 persons, 30 with and 30 without sleep disorders, from the three exposure zones A, B and C. In the cow study 5 exposed and 5 unexposed animals were surveyed. During the 10-day period the human volunteers kept a diary on sleep quality and delivered their early morning urine for testing on 6OHMS, a metabolite of melatonin. The hypothesis was that a chronic effect leads to a gradient with low levels of melatonin in Zone A and higher levels in Zones B and C and that the acute effect was expected to increase melatonin levels during the 3-day period with no emission.

The study on *blood pressure* verification examined whether self-reporting is a reliable indicator of hypertension in the surroundings of the shortwave transmitter. Using this information we tested whether after 'measurement error' correction, there still remained a gradient between $A > B > C$ as shown in Study I. The idea was to measure blood pressure of all volunteers from Study I who claimed to suffer from hypertension, and of an equally sized population without any indications of hypertension.

By conducting the study on well-being of schoolchildren we tried to obtain some evidence on changes in mental functioning of children in the surroundings of the Shortwave Transmitter. The promotion rates from primary to secondary school in the primary schools in Mamishaus (Zone A) and Moos (Zone C) in the period 1954 - 1993 were compared. Direct tests of mental functioning were not performed in view of the small number of children and the heterogeneity in terms of exposure history.

3.3 Design of exposure measurements

3.3.1 Study I

In order to assess the exposure, 55 measuring sites in the three zones were selected. Six were allocated in Zone C, 27 in Zone B and 22 in Zone A. Measurements were done closed to the sites where the study participants lived. This approach was fixed with regard to the importance of sampling rather than according to a systematic grid. Measurements were made *outdoors* in order to measure the undisturbed field.

3.3.2 Study II

In order to measure EMF-exposure as closely as possible to where the individuals of Study II lived, exposure measurements were performed in bedrooms of the volunteers. For administrative and logistic reasons the exposure measurements had to be done during 6 weeks following the experimental period.

3.4 Design of laboratory determinations

Melatonin and its metabolites are measured either by means of enzyme-linked-immuno-absorbent-assay (ELISA) or with the help of radio-immuno-assay (RIA). For 6-Hydroxy-Melatonin-Sulfate determination (6OHMS) - a metabolite of melatonin - in early morning urine we selected ELISA produced by Repromed Hamburg.

The test is done on a plastic plate, called microtiter plate, with 92 to 96 wholes depending on the laboratory equipment. A maximum of 92 to 96 determinations can thus be obtained simultaneously. However, not all 96 (92) wholes were available for testing the samples. A duplicated standard curve consisting of 8 different standard 6OHMS-dilutions had to be determined on each microtiter plate. In addition 2 internal controls of known concentration had to be determined on the same plate, one with a low and one with a high concentration of 6OHMS. These controls had to be repeated at least once on each plate. In principle $60 \times 10 \times 2 = 1200$ tests had to be assigned to the microtiter plates. While assigning samples to a plate we had to consider the fact that the variation on a microtiter plate was smaller than the one between the plates. Since we wanted to test the chronic as well as the acute effect of EMF-withdrawal on melatonin levels we considered the following 4 assignments:

1. *Random assignment:* The urine samples of one person are assigned randomly to a microtiter plate and repeated on the same plate. This option allows 36 respectively 38 samples to be determined simultaneously, which means 19 microtiter plates must be tested.

2. *Fixed day assignment:* All samples from the same day are tested on the same microtiter plate and repeated on another one. This assignment requires at least 20 microtiter plates.

3. *Fixed person assignment:* 10 samples of the same person including the repetitions are measured on the same microtiter plate. This assignment requires testing of 22 microtiter plates.

4. *Fixed day and person assignment:* The 10 samples of the same person are assigned to one microtiter plate, the replications to another one. This allows to test 7 persons on the same microtiter plate. When these 7 persons are uniformly distributed over the exposure range acute and chronic effects should be detectable. This assignment requires 19 microtiter plates.

3.4.1 Study II

The 6OHMS-ELISA was evaluated and improved by U. Rogger and Prof. Dr. med. H. Gerber at the Division of Protein and External Analysis of Central Chemical Laboratory of the Bern University Hospital (Inselspital). Creatinine measurements were performed at the same Laboratory. Finally, all urinary samples were tested according to the fixed day and person assignment at the manufacturer of ELISA (Repromed Hamburg) by A. Wunderlich and B. Manz, Ph.D.

The assignment was done as follows:

1. the whole study population was arranged according to exposure,

2. systematic random urine samples of 7 volunteers were assigned to one microtiter plate.

3. This microtiter plate was repeated three times.

On each plate there are 76 test places (wholes). The assignments to a whole on a microtiter plate were randomized by means of the random number generator of Splus 3.2 for Windows 3.1. When the internal controls indicated that the microtiter plate was not reliable, examination of the whole plate was repeated. When a test result revealed that the reproducibility was lower than in the other samples, that particular measurement was repeated three times with the same test set.

Because the analysis of the tests from Hamburg indicated that both acute and chronic effects were not significant whereas the results from Bern suggested a significant acute and chronic effects, the tests of the urinary samples of the first two days were repeated according to the *fixed day assignment.*

3.4.2 Bovine samples

The bovine study consists of a comparative study of plasma samples versus saliva samples and a follow-up of night salivary samples in 1-hour intervals during the ten days of the study. These tests were carried out with the help of the radio-immuno-assay (RIA) by A.Wunderlich, Repromed Hamburg, under the supervision of Dr. B. Manz, with focus on the acute effect.

On each microtiter plate 156 tests could be done. We measured every sample twice. The cows were surveyed during 10 nights. Each night 7 salivary samples were collected. Our study included 10 cows, 5 exposed and 5 unexposed. This lead to 1400 salivary samples which had to be assigned to the microtiter plates. The decision was taken to measure all 140 samples from one cow on any microtiter plate. To compensate for a potential learning process of the technician the order of the 10 cows was fixed (exposed - unexposed - exposed -...- unexposed).

3.5 Statistical Analysis

Since every part of the study has its specific features and problems, the applied statistical methods are described in the corresponding chapters. In principle the applied statistical models were made as simple as possible. Wherever possible, the comparison between exposed and unexposed population was expressed by means of Odd's ratios [OR]. Consider the 2 × 2 table

	ill	healthy	Total
Exposed	a	b	a+b
Unexposed	c	d	c+d
Total	a+c	b+d	n

then the Odd's ratio OR is defined by

$$OR = \frac{a \cdot d}{b \cdot c}.$$

This simple model with the category 'exposed/unexposed' as explanatory variable can be extended to a continuous variable by means of logistic regression. Consider the binary outcome Y and the continuous explanatory variable X: the logistic model estimates the effect of X on the expectation of Y noted $E(Y)$ by

$$\ln \frac{P(Y = ill|X)}{P(Y = healthy|X)} = \beta_o + \beta_1 \cdot X.$$

β_o is an estimator of the overall prevalence of the disease, and β_1 estimates the influence of X on Y. In this regression model the OR is not constant but increases or decreases according to

$$OR = e^{\beta_1 \cdot X}.$$

This model can be extended to the multivariate case with multiple explanatory variables as well as to the case of correlated observations such as short time series observed in the same person or animal (generalized estimating equations).

Chapter 4

Exposure assessment

R. Coray, J. Baumann

4.1 General considerations

4.1.1 Relevant properties of the electromagnetic field

The electromagnetic field (EMF) consists of two components: the electric E-field and the magnetic H-field. Their vectorial product (poynting vector) describes the power density and direction of the electromagnetic wave. In a far-field situation there exists a simple and constant relation between the E- and H-vector with respect to magnitude, direction and phase. In near-field situations, however, the E- and H - field may be decoupled. Both quantities must be measured in the latter case if the field is to be sufficiently characterized. Near field situations are present close to the transmitting antenna and inside buildings [BUWAL (1992), EMC 94 ROMA (1994), EBU (1995)].

Coupling of EMF with biological bodies depends on the field strength, frequency, polarization of the field as well as on the size of the person and its orientation relative to the field.

With respect to potential non-thermal effects, the amplitude modulation might additionally be of importance.

4.1.2 Purpose of the measurement campaign

The purpose of the measurement campaign was to obtain quantitative information on the exposure of the study population to EMF originating from the shortwave transmitter station. Initial attempts to estimate exposure levels simply by distance criteria were given up due to the complex nature of the radiation pattern which changes both temporally and spatially.

In the context of the preliminary study a screening of the whole study area was performed with emphasis on those spots where study participants lived. Given the number of locations and of different radiation patterns to be covered an exposure metric was needed which could be considered as reasonably representative for the exposure and which at the same time was easily accessible to measurement in a routine procedure. The magnetic field strength at the frequencies of the shortwave transmitter, outside inhabited buildings, was chosen as the quantity to be investigated. The magnetic field is little influenced by natural or man-made objects and is in general relatively homogeneous over distances of several tens of meters.

The purpose of the Study II was to gather more precise exposure data on individual persons during a clearly defined period of time (night hours) and in a precisely known location (bedroom). Consequently, in order to perform measurements within buildings, a highly sophisticated measurement system was developed and applied which allowed simultaneous measurement of the electric and magnetic field strength. In addition to measurements numeric simulations of the field distribution in a typical bedroom were carried out with the aim of quantifying the variability of field distributions within buildings and of coupling of the EMF to humans [Swiss Telecom PTT (1994), IEEE (1993), EMC Baden Bericht No. 93028].

4.1.3 Exploitation of the Shortwave Transmitter station

The Schwarzenburg shortwave transmitter covers exclusively overseas regions. In general, the direction of emission changes every 2 hours. A maximum of three 6.1 - 21.8 MHz transmitters with output powers of 150 kW operate simultaneously at the Schwarzenburg complex. Three curtain-array antennas, arranged in a classic "star-configuration", enable to direct the emission into almost any horizontal angle at intervals of 15^0. The main beam is normally adjusted for an elevation of 11^0; areas at ground level in the proximity of the antennas are thus not directly exposed to the main beam, but to a complex "stray field", composed of main beam components and unintended side and back lobes from the three simultaneously working antennas. Generally one emission period lasts 105 minutes and is followed by a silent period of 15 minutes,which allows to change the direction and frequencies (see Figure 4.1).

4.1.4 Dosimetric aspects

Given the field strengths measured in the study area, thermal effects of EMF can almost certainly be excluded. Any biological effects must therefore be of non-thermal origin. Up to now neither the site of primary interaction on or within the body nor the decisive physical parameter or combination of parameters are known for such effects. The magnetic and electric field strength values which have been measured in the measurement campaigns are to be considered as a surrogate for the "real" dosimetric quantity acting

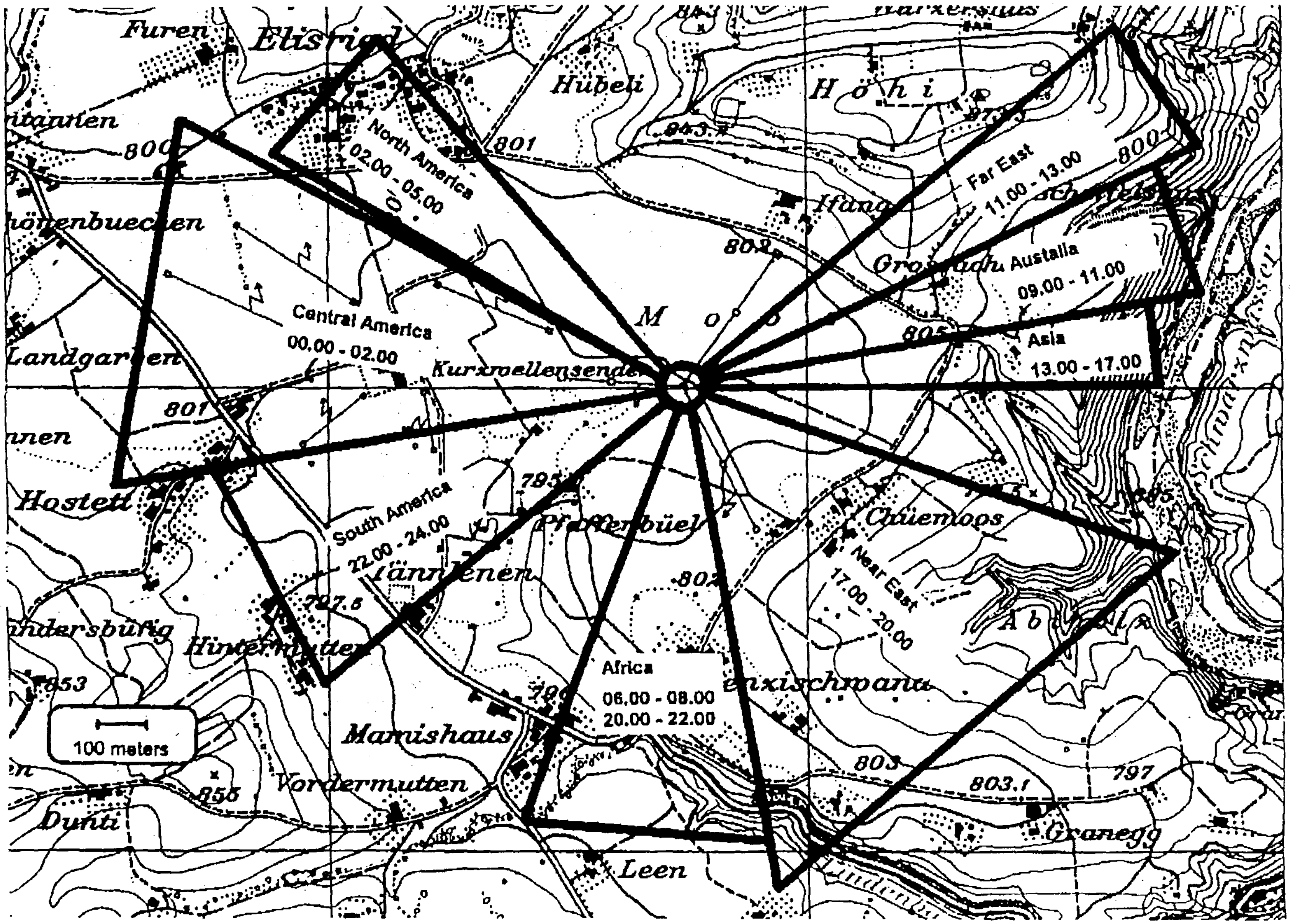

Figure 4.1 : Exploitation of the Shortwave Transmitter Station
(Reproduced with the permission of the Federal Office of Topography of June 30, 1995)

within the body, if such a quantity exists at all.

It is of interest to investigate the correlation between the measured field quantities and hypothetical dosimetric quantities. Simulations of this kind were performed for a few selected dosimetric parameters by means of numerical techniques for modelling the EMF distribution around and in human bodies [EMC Baden No. 93028].

4.1.5 Uncertainty of exposure assessment

Any determination of exposure is necessarily subject to some uncertainty. There are several factors contributing to the overall uncertainty:

1. Calibration and measurement uncertainty.
2. Uncertainty about the spatial representativeness if the measurement is not taken exactly at the position of the study person.
3. Uncertainty about the temporal representativeness if spot measurements are performed, not coincidental with the medical assessment.
4. Uncertainty about the representativeness of the measured parameter for the dosimetrically relevant quantity.
5. Uncertainty about the actual stay and moves of the study person within the field.

An estimate of the uncertainty is desirable for two reasons:

1. In order to comply with exposure limit values, a conservative approach requires the sum of the measured field strength plus the measurement uncertainty to lie below the limit value [BUWAL 1992]. In compliance testing the measurement should be performed at the time and at the location where maximum field strength is to be expected and where the person can stay. The quantity to be measured is defined by the standard. Consequently, only the calibration and measurement uncertainty need to be considered (see Table C.1 in Appendix C, Pos. 1.6).
2. In a statistical analysis an approximate knowledge of the exposure data variance is of interest. It enables to estimate the resolving power of the study and helps identify those aspects which may need further refinement. For the statistical analysis all random uncertainties should be included which cannot be controlled for by the study design.

In the preliminary study this approach was not yet developed. Furthermore it was assumed that the variance in exposure is dominated by the uncertainty about the exact stay of the (moving) study persons, which is almost impossibly to estimate based on the available data. Uncertainties are therefore restricted to the technically related contributions of the measurement system [Swiss Telecom Bericht No. 31002, 31005 (1992), Swiss Federal Institute of Technology Zürich] .

In Study II the position of the sleeping person was fixed and known. Under these circumstances further considerations about the temporal, spatial and dosimetric representativeness of the measured value are warranted [Swiss Telecom No. 44403, EMC Baden No. 93028, EMC Baden No. 941 231 (1994)].

The individual uncertainties and variations are characterized by a range of possible values. The boundaries of this range are understood to reflect the worst case; usually no detailed knowledge of the probability distribution within the range is available. A conservative approach assumes that the probability distribution is uniform between the lower and upper boundary and zero outside. For this type of distribution the standard deviation can be easily calculated by

$$\sigma = \sqrt{\frac{(b-a)^2}{12}},$$

where a and b are the lower and upper boundaries.

Several contributions to the overall uncertainty are combined on assumption that the individual contributions are statistically independent. The overall standard deviation is then obtained by taking the square root of the sum of the variances of the individual contributions. In Appendix C both, the estimated worst case range and the standard deviation, are listed.

4.1.6 Background field strengths

Any location in Switzerland, whether in the neighbourhood of a transmitter or not, is subject to a background electromagnetic field originating from all shortwave transmitters all over the world. It appears reasonable to limit the study area to such an extent that the exposure from the investigated shortwave station is at least of equal magnitude as the background to which everyone is exposed.

Although an annual profile of radio frequency field strengths including the shortwave band had already be monitored at another place in Switzerland [Baumann et al. 1993], it was decided to utilize the 3-day shut-down of the transmitter during Study II to measure the background levels in the study area as well [Swiss Telecom PTT, No. 44403, EMC Baden No. 93028].

For the measurement of these relatively low field levels standard measuring equipment was used. Many spectra, recorded at different times during the 3-day measurement period, were individually integrated between 3 and 30 MHz. Day to night variations amounted to approximately 17 dB (corresponding to a factor of 7 with respect to field strength). The 24-hour average was found to be 0.083mA/m (see section 4.4).

4.2 Study I

4.2.1 General Aspects

Within the scope of Study I a screening of the whole study area was performed with the emphasis on domiciles of the study participants. Since the number of locations and of different radiation patterns had to be covered, an exposure metric was of need which was reasonably representative for the exposure, and at the same time easy to access in a routine procedure. The magnetic field strength at the frequencies of the Shortwave Transmitter, outside of inhabited buildings, was chosen as the quantity to be investigated. The magnetic field is little influenced by natural or man-made objects and is in general relatively homogeneous over distances of several tens of meters.

The determination of the EMF-exposure has been done by the Swiss Telecom PTT under the supervision of the ETHZ (Swiss Federal Institute of Technology in Zürich) [Swiss Telecom No. 31002, 31005, 31007, Swiss Federal Institute of Technology Zürich (1993)].

4.2.2 Measured field property

The magnetic field strength was measured selectively at the broadcast frequencies of the Shortwave Transmitter in three orthogonal directions. All components were combined numerically according to the guidelines of IRPA [1988] and other exposure limit standards, whereas phase shifts were neglected. This procedure yields the so called, equivalent field strength. The equivalent field strength H_{eq} in the case of 3 frequencies is defined by

$$H_{eq} = \sqrt{\sum_{fi=1}^{3} H_{x,fi}^2 + H_{y,fi}^2 + H_{z,fi}^2},$$

where fi notes the three measured frequencies under consideration and x, y and z the three orthogonal components of the H-field. Modulation parameters were not considered.

4.2.3 Temporal aspects

With the oversea regions as its target zones, the Schwarzenburg Transmitter directs its emissions in time intervals of generally 105 minutes, followed by a 15-minute break, into different directions of the earth. Consequently, field levels at a given measuring point vary strongly with time. According to the measurement protocol at least one spot measurement was done for each of 22 distinguishable exploitations (11 for normal schedule and 11 for experimental schedule during the diary program) at each measurement point. Reproducibility at the same location and during the same transmitter status was checked by repeated measurements and found to be good. Consequently, further on only single spot measurements were done with no time averaging. A certain spot measurement was then assigned to the whole period of one exploitation status at a given location. Based on these values time averages were calculated for the 24-hour period, for day-time and night-time hours (linear averaging was applied; for the 15-minutes break between emissions the independently determined background exposure was taken as the relevant exposure level).

For practical reasons the field measurements could not be completed during the medical interview and diary programs. Data were collected mainly during a 3-month period in the course of and after the medical investigation program.

4.2.4 Measurement locations

Measurements were done outdoors, at 56 points in the vicinity to inhabited buildings. 49 points were located in Zones A and B, 6 in Zone C and 1 in the gap between Zones B and C (see Figure 4.2). In order to obtain a field value representative for a given location any local disturbances of the EMF had to be avoided. Consequently the measuring location was chosen well away from any metallic objects as e.g. fences or overhead power lines. The field levels were recorded at 1.5 meter above the ground level.

4.2.5 Measurement system

For field levels above approx. 25 mA/m the broadband measurement system described in Section 4.3.5 was applied. The measurement uncertainty (including calibration and measurement system specifications), expressed as ± 2 standard deviations, is ± 2.9 dB (see Appendix C).

For lower field levels a high precision magnetic loop antenna system in connection to a measuring receiver was applied (see Appendix A.1). Since the determination of the equivalent field strength requires separate measurements of the three field vector components for each frequency of interest, the loop antenna had to be mechanically turned into the three orthogonal axes. Contrary to often applied broadband measuring equipment (recording the sum of all signals within a certain band of frequencies), the above described measuring system enables frequency selective measurements. As a result it was possible to record selectively the EMF caused by the Schwarzenburg Transmitter only. The measurement uncertainty for this system, expressed as ± 2 standard deviations, is estimated as ± 2.4 dB [Swiss Telecom No. 31002, 31005, 31007, Swiss Federal Institute of Technology Zürich].

4.2.6 Measured field levels

Over a period of about 90 days, a total of 2621 field strength levels were recorded.

The highest field strength amounted to 51 mA/m; adding the measurement and calibration uncertainty of ±2.9 dB (twice the standard deviation, following the recommendation of [BUWAL 1992]) gives a conservative value of 70 mA/m. The field strengths measured inside Zone A do therefore not exceed the exposure limit value of 73 mA/m recommended by [IRPA 1988] and [BUWAL 1990].

In Zone B field levels are generally lower than in Zone A but still above the background level.

As to Zone C, some immission levels slightly exceed the background level in dependence on the time of day. In the light of this finding, the distance of Zone C to the antenna may have been chosen too small (see section 4.4). In general a good 1/distance dependence of the undisturbed magnetic field strength was confirmed (see Figure 4.3).

4.2.7 Uncertainty of exposure assessment

The uncertainty of the measurement system has been presented above. In addition, depending on the height of an apartment above ground, a deviation between the real field strength and the one measured at the height of 1.5 m above ground should be taken into account. As the major uncertainty of exposure assessment, however, is considered to be the lack of knowledge about the actual stay of the study subjects. Not enough data have been collected from the study population to allow the assessment of this variability. In the scope of this preliminary study no further attempts were therefore made to quantify the overall uncertainty of exposure assessment [Swiss Telecom No. 31007].

4.3 Study II

4.3.1 General aspects

In contrast to the preliminary study, the purpose of the follow-up study was to gather more precise exposure data of individually investigated persons during a clearly defined period of time and in a precisely known location. As outlined above, near field situations and inhomogeneous field distributions can occur inside buildings. The approach chosen was to measure the electric and magnetic field strength in the bedroom and to simulate the spatial inhomogeneity and the coupling to the sleeping person using numerical methods. Measurements were performed in each bedroom used by the study participants while the computer simulations were carried out for one selected configuration with the aim of exploring the additional variability with regard to hypothetical dosimetric parameters [EMC Baden No. 93028, EMC Baden No. 941231].

EMF measurements were carried out by the Swiss Telecom PTT, simulations were performed by EMC Baden; both projects were supervised by the EPFL (Swiss Federal Institute of Technology in Lausanne) [Swiss Telecom No 44403, EPFL (1994), EMC Baden No. 93028].

4.3.2 Measured field properties

The RMS electric and magnetic field strengths were measured simultaneously and at the same position by means of the broadband measurement system described below. This system provides individual readout of the 3 orthogonal field components of the electric and magnetic field vector as well as the equivalent field strength as defined by IRPA [1988] and other exposure standards, neglecting phase shifts between the spatial field components (see Appendix A and B). The polarization state can therefore not be determined from these results. Its influence on the hypothesized dosimetric quantities must be modelled through computer simulations [EMC Baden No. 941231].

Modulation parameters were not considered.

4.3.3 Temporal aspects

With the oversea regions as its target zones, the Schwarzenburg Transmitter directs its emissions in time intervals of generally 105 minutes, followed by a 15-minute breaks, into different directions of the earth. Consequently, field levels at a given location vary strongly with the time.

The measurement system was programmed to record the E- and H-field simultaneously every 15 minutes during night hours between 18.00 and 06.00 local time. Reproducibility during one and the same exploitation state of the transmitter was excellent. All field strength values measured at a given location and referring to the same exploitation state were linearly averaged. For the 15 minutes break between emissions and for field levels below the sensitivity of the measurement system the independently determined background exposure was taken as the relevant exposure level.

For practical reasons the field measurements could not be carried out at the same time as the collection of the urine samples. The time lag was maximum 6 weeks [Swiss Telecom No. 44403].

4.3.4 Measurement location

In order to avoid coupling of the sensor system to nearby conductive objects, it was placed 1 meter away from the sleeping person and such objects, usually in the middle of the bedroom [Swiss Telecom No. 44403](see Figure 4.5).

4.3.5 Measurement system

A recently developed broadband system was applied which allowed simultaneous measurement of the electric and magnetic field strength (Appendix A.2). Its sensitivity is 0.1 V/m for the electric and 0.5 mA/m for the magnetic field. The readout of the data is by fibre optic and the system is completely remote-controlled. A 1 m distance from conductive objects must be kept. The measurement uncertainty, expressed as 2 standard deviations, is ±2.9 dB (Appendix C).

4.3.6 Measured field levels

E- and H-field measurements have been performed inside 41 bedrooms around the Shortwave Transmitter resulting in a total of 1578 records (see Figure 4.6). The maximum field strength levels were found to be 7.55 V/m for the E-field and 23.6 mA/m for the H-field. These field-levels, including the measurement uncertainty, do not exceed the exposure limits of IRPA (see Figure 4.6)[Swiss Telecom No. 44403].

4.3.7 Uncertainty of exposure assessment

The measured field parameters at a distance of 1 m from the sleeping person may represent the biologically active metric only to an approximate degree. The correlation is degraded by field inhomogeneities between the point of measurement and the study person, by long term variations of the propagation characteristics of the electromagnetic waves and by variable coupling of the field with the human body and other conductive objects. The field coupling with the human body depends on body size, structure and orientation relative to the field, on the presence of conductive objects close to the person, on the hypothetical site of interaction within the body or on its surface as well as on frequency and polarization of the EMF [EMC Baden No. 93028, 941231].

Rough estimates for these uncertainties were derived from model calculations or obtained on the basis of experience; they are compiled in Appendix C. If the human head is taken as the hypothetical site of interaction, a total uncertainty of exposure assessment, expressed as 2 standard deviations, of ±6 dB for the magnetic field and ±12 dB for the electric field is predicted. This uncertainty could be narrowed if the sites of interaction were known more precisely and if dosimetric calculations were performed on a subject by subject basis, controlling for as many of the variables that define the coupling of the field with the human body.

4.4 Background field level of the H-field

During the 3-days of Study II when the Transmitter was turned off, background field levels of the H-field were measured. The components H_x, H_y and H_z were consecutively measured with 3 orthogonal magnetic loop antennas with the following specifications:

- frequency range: 3-30 MHz;
- measuring bandwidth: $\Delta f = 30\ kHz$
- frequency step: $\delta f = 30\ kHz$
- measuring time: (1 cycle from 3-30 MHz):
  - =15 seconds for 1 H field component.
  - =60 seconds for all three H field components.

The equivalent field strength H_{eq} is obtained by summing over the whole frequency range 3 to 30 MHz.

$$\begin{aligned} H_{eq} &= \sqrt{\frac{1}{\Delta f}\left(\sum_{f=3MHz}^{30MHz} H_x^2 \cdot \delta f + H_y^2 \cdot \delta f + H_z^2 \cdot \delta f\right)} \\ &= \sqrt{\sum_{f=3MHz}^{30MHz} (H_x^2 + H_y^2 + H_z^2)} \end{aligned}$$

This led to the following values of H_{eq}:

minimum value of H_{eq}	0.041	mA/m
average value of H_{eq}	0.083	mA/m
maximum value of H_{eq}	0.168	mA/m

A 24h-profile is displayed in Figure 4.7.